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Robust Engineering of Deep Drilling Process by Surface State Optimization

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Abstract

The off-line quality engineering is an important aspect that regards the manufacturing engineering process optimization. This target may be achieved by implementing the robust engineering principles. Therefore, the present paper reflects the results of the Taguchi Method approach applied for a fractioned factorial designed experiment in case of deep peck drilling with a twist drill, of a composite material. The scope was to optimize the surface state, characterized by his roughness, optically measured.

Keywords: quality engineering; surface state; deep hole drilling.

1. INTRODUCTION

The present paper presents a part of a research project, developed in a plant belonging to a multinational supplier from the automotive industry. The need to develop those researches was born from the fact that a relatively new type of material (a composite polyurethane material) was machined on a high speed flexible manufacturing system. For this type of material, in the technical literature, there are no precise recommendations for the cutting parameters [1]. Maximum efficiency of the research was obtained by using the Taguchi's Method.

Similar problems can be solved by implementing several types of experiments design types and of data analysis methods. The Taguchi's Method was selected because of his efficiency, his power and the results obtained (spending less resources of: money, time, materials, machine hours, labor, tools, etc.).

Practically, this is the reason why several researches try to implement the robust engineering with Taguchi's approach, in their works [2-5].

The means of characterizing the process are varied, speaking about the research methodology or about the design of experiments methodology. Therefore, [6] studies the main influence parameters on the deep drilling monitoring the cutting force, taking account of the cutting fluid used and [7-8] studies new deep drilling tools designs. Another studies [9] are developed for special situations, for example the case of the holes with very small diameters monitoring systems, based on machine integrated sensors.

A comprehensive state of the art of the methods and means used for monitoring and charactering the cutting process by the surface's roughness is provided by the [10].

In restrictive situations the surface quality can be characterized not only by his surface state but by his integrity, too [11].

2. METHODOLOGY

2.1. The machining theory considered

The deep drilling process is characterized by several critical aspects:

- The tool is immersed in the workpiece, leaving no view of the operation;
- The chips must be controlled as form (continuous bands) and type (fragmented, but not very short);

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- The chip evacuation is essential because it affects the hole's machined surface's quality, tool life and reliability;
- The cutting speed for the tool decrease from the maximum value at the drill's periphery to zero at the rotational centre point (the midpoint of the chisel edge). Also, the tool's geometry varies along the main cutting edge and is totally different at the chisel edge level. Thus, the conditions that characterize the chip's formation are different along the cutting edges length.

Despite the fact that for deep hole cutting is recommended the use of the coolant supply, for this application it is excluded, because the material tested can be only dry machined.

According with the machining theory [12], there are two methods for peck drilling the deep holes with twist drills:

- To achieve maximum productivity (Fig. 1), the drill must not be retracted more than 0.3 millimeters from the hole bottom. Alternatively, it will be made a periodical stop, while the drill is still rotating, before continuing to drill.
- To achieve the best chip evacuation (Fig. 2), after each drilling cycle, the tool will be retracted out from the hole to ensure that no chips are stuck onto the drill's flutes.

Productivity in drilling is strongly related to the penetration rate, which is, also, one of the main influence factors for the surface quality and is one of the main means for controlling the chip's length and, therefore, their jamming in the drill's flutes.

The cutting speed, especially for deep drilling, is very important for the chip's evacuation, which is relatively bad at lower levels. For the tested material, this parameter is not crucial for the tool's life, but at higher levels, because of the temperatures, the surface will be machined at a poorer quality level (the chips can be melted and glued on the tool and the already generated area of the hole).

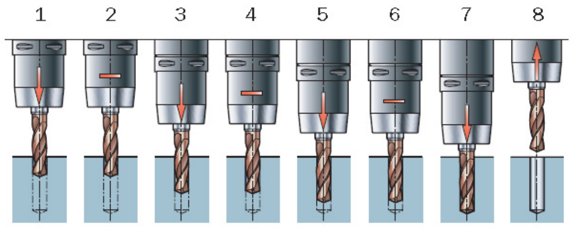

Fig. 1. Peck drilling method, for the best productivity [12]

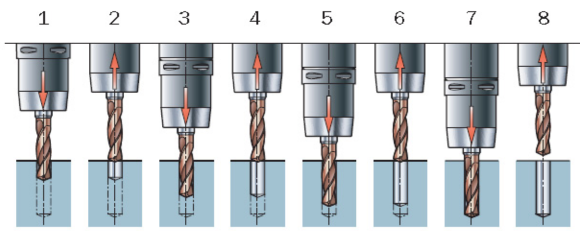

Fig. 2. Peck drilling method, for best chip evacuation [12]

2.2. Robust Engineering by Taguchi Method – the applied methodology

In a very brief presentation, the sequences of the applied method are:

- The choice of the levels values for the experimental parameters;
- The choice of the experimental array;
- The run of the experiment's trials;
- The data measurement, analysis and interpretation.

The experimental array used is presented in the Table 1. It is an $L_4(2^3)$ lattice, that involves: 4 trials, 3 experimental parameters, each one tested at 2 levels.

The three experimental parameters are:

- The number of drill's withdraws,
- The number of rotations per minute and
- The cutting feed speed (the penetration rate) of the cutting tool.

These values are selected based on data from the technical literature [1], in this case the cutting tool's producer. The choice of these values is for the "thermoplastics" group of materials, which include the tested material, too. The values presented in the catalogues are generic, and these must be particularized and optimized for the application.

For each one of the four trials, the cutting process was repeated 10 times, in the same conditions, resetting all the process's parameters after each drilled hole. For each trial it was calculated the average, the standard deviation and the S/N ratios for the 10 measured values at each one of the four trials.

The Tables 5, 6, 7 and 8 present all the results of the measurements (for the researched critical quality characteristic, the mean average roughness, and the R_a parameter) realized on the generated surface.

Table 1. Factorial fractionated experimental array, $L_4(2^3)$ – the values of the factors levels, for the deep hole drilling

Controlled factor Trial no.	Number of withdraws	Rotations Per Minute [rot / min]	Cutting Feed [mm/min]
1	- (A1)	+ (B1)	+ (C1)
2	- (A1)	- (B2)	- (C2)
3	+ (A2)	+ (B1)	- (C2)
4	+ (A2)	- (B2)	+ (C1)
Level -	4	2000	120
Level +	5	2500	160

2.3. The test piece

Figure 4 presents the test piece prepared for being measured. Here are represented the holes for the first trial, measured in three points one by one, at the specified levels.

Fig. 3. The machined test piece

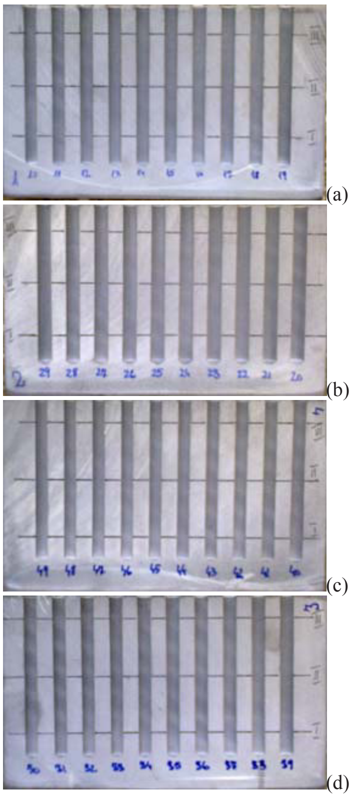

Fig. 4. The test peace prepared for measurements: the first trial (a), the second trial (b), the third trial (c) and the fourth trial (d),

2.4. The measurements

The measurements were performed with a reliable optical measurement equipment (see Fig. 5), Wyko NT1100, with a magnification rate of 20X.

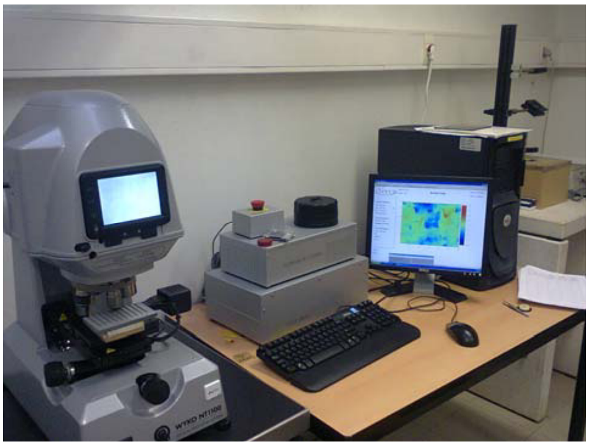

Fig. 5. The optical measurement equipment

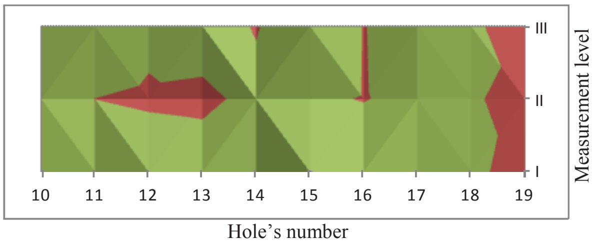

Fig. 6. The contour chart of the Ra [μm] values for the first trial

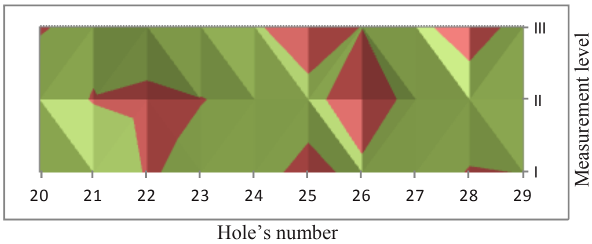

Fig. 7. The contour chart of the Ra [μm] values for the second trial

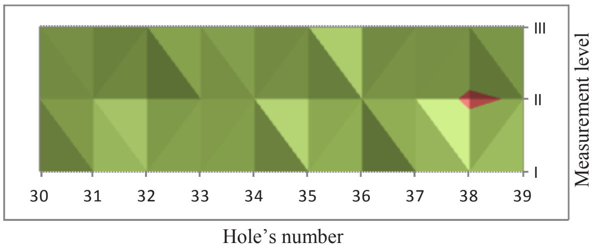

Fig. 8. The contour chart of the Ra [μm] values for the third trial

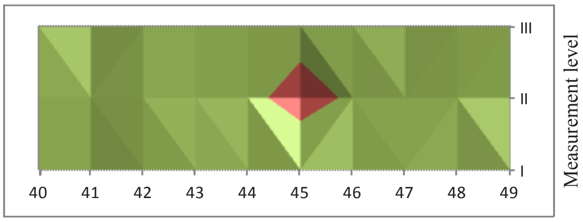

Fig. 9. The contour chart of the Ra [μm] values for the fourth trial

The Figures 6, 7, 8 and 9 present the contour plots for each 4 trials, for all the 10 measurements at each level (the start, the middle and the end of the machined holes – see Fig. 4). It can be observed that most part of the measurements are contained on an average range of values, therefore, aberrant values were not discovered (the experimental data is presented in the Tables 5, 6, 7 and 8).

2.5. The data analysis

For minimizing the measured critical quality characteristic, is used the Equation 1 [12], to compute the S/N ratio for the "Smaller – The - Better" case. This is the indicator that will be used to take the correct decision for choosing of the experimental parameter's optimal level.

$$S/N = -10 \cdot \log\left(s^2 + \overline{y}^2\right) \qquad (1)$$

Table 2. The experimental data and the results of the S/N ratios ("Smaller-The-Better" case)

Trial no.	Average	Standard deviation	S/N ratio
	[μm]	[μm]	[dB]
1	4,459	0,67467	-13,08
2	4,220	0,49807	-12,56
3	4,880	0,58656	-13,83
4	4,855	0,49486	-13,76

Table 3. Average effects [μm] of the tested factors

Average effects of experimental data	Average effects of each factor	Average effects of each factor and each level
A1ave = 4,86733	Aave = 4,60358	EA1 = 0,26375
A2ave = 4,33983		EA2 = - 0,26375
B1ave = 4,53750	Bave = 4,60358	EB1 = -0,06608
B2ave = 4,66967		EB2 = 0,06608
C1ave = 4,65700	Cave = 4,60358	EC1 = 0,05342
C2ave = 4,55017		EC2 = -0,05342

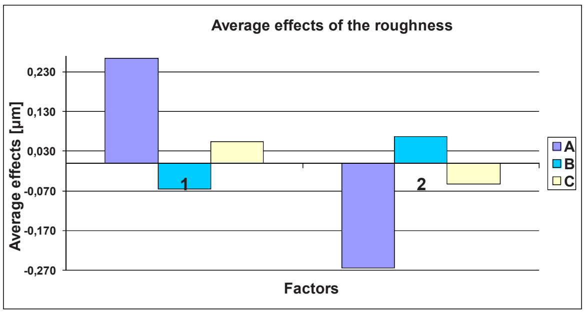

Fig. 10. The average effects of the roughness

Table 4. The average effects [dB] of the S/N ratios

Average effects of experimental data	Average effects of each factor	Average effects of each factor and each level
A1ave= -13,79939	Aave= -13,31237	EA1= -0,48702
A2ave= -12,82535		EA2= 0,48702
B1ave= -13,16754	Bave= -13,31237	EB1= 0,14482
B2ave= -13,45719		EB2= -0,14482
C1ave= -13,42589	Cave= -13,31237	EC1= -0,11352
C2ave= -13,19885		EC2= 0,11352

The Tables 3 and 4 presents the results obtained after computing the measured experimental data. In this connection, there were computed the average factor's effects and the average effects of the S/N ratios *(1)*. After that, it was possible to choose the optimal factor's combination and to estimate the optimal levels of the targets of the quality characteristic.

In the Figures 10 and 11 are graphically represented the statistics computed: the average effects of the Ra roughness and the average effects of the S/N ratios for the same measured quality characteristic.

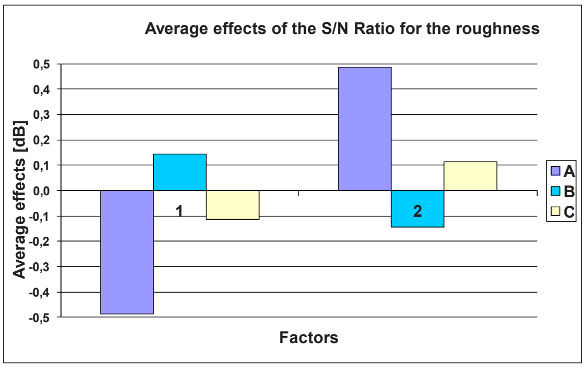

Fig. 11. The average effects [dB] of the S/N ratio for the roughness

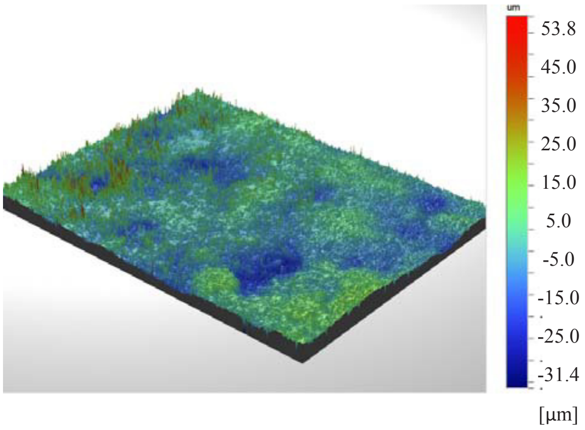

Fig. 12. The Three-Dimensional view of the scanned surface

The Figures 12 and 13 present a sample of a measurement provided by the Vision 3.0 for NT1100 software, which helps to analyze the optically measured roughness. From both the previously mentioned figures, it can be observed the proper adjustments setups of the microscope, provided by the operator, and the local defects, that can be excluded from the evaluation.

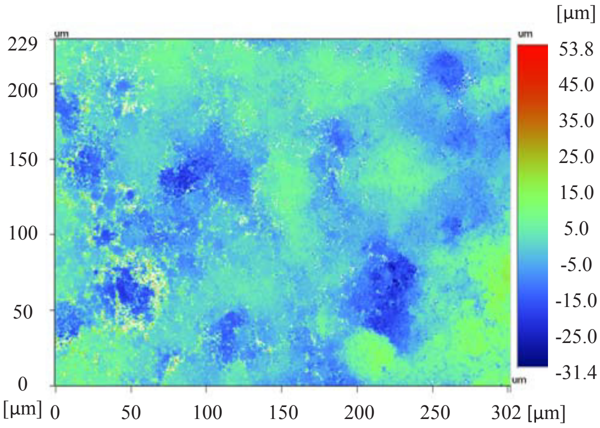

Fig. 13. The Bi-Dimensional view of the scanned surface

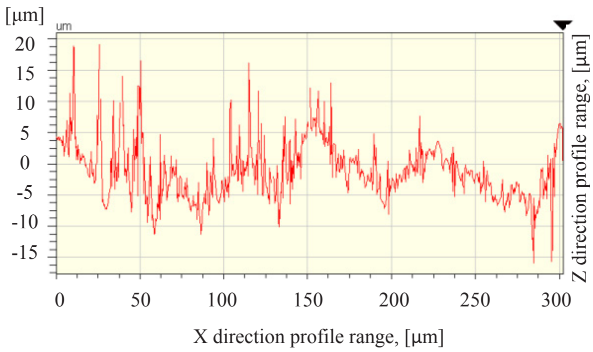

Fig. 14. X direction profile at the level of a sector of the scanned surface

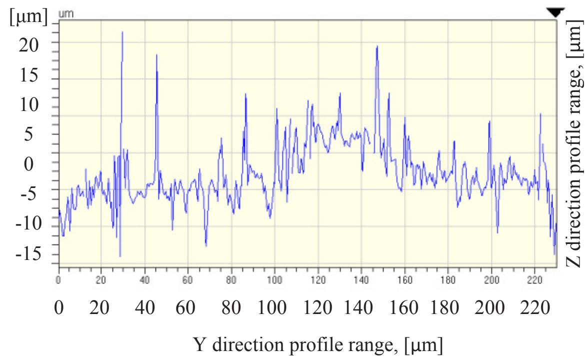

Fig. 15. Y direction profile at the level of a sector of the scanned surface.

The Figures 14 and 15 underline that the profile can be analyzed graphically, not only tri-dimensionally. For each measured point, it can be analyzed bi-dimensionally, on both the X and Y directions of the optically scanned surface.

3. RESULTS

According with the Figure 11, the optimal combination for the tested factors is A2B1C2, that means:

- A2 = 5 withdraws;
- B1 = 2500 revolutions / minute;
- C2 = 120 mm / minute.

It means that the hole's drilled surface state quality will be higher because of a:

- Higher number of withdraws (better flushing of chips though the twist drill's flutes, even if there is susceptible to register more interferences between the cutting tool's secondary cutting edges and the already generated area of the surface);
- Higher cutting speed (higher productivity) and
- Lower cutting feed (higher number of passes for generating the hole).

By applying the optimal setup parameter's configuration, after the confirmation test, the estimated roughness must be Ra = 4,98683 µm for a S/N Ratio = -13,9442 dB.

4. CONCLUSIONS

The article present the results of a research project, implemented at industrial level.

Practically, the Taguchi Method can help a lot of industrial specialists to solve their problems; the strong point of this approach is that, it brings some pure research tools, complicated or relatively complicated, in the industrial field. Only with some basic knowledge of statistics, but with a professionally attitude toward the experimental research, the industrial specialists can bring solutions to specific problems in an efficient manner.

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Appendix A. Experimental results

Table 5 contains the experimental results obtained by measuring the Ra [μm] roughness parameter. Therefore:

- The holes number 10 ... 19 refers to the results obtained for the first trial;
- The holes number 20 ... 29 refers to the results obtained for the second trial;
- The holes number 30 ... 39 refers to the results obtained for the third trial;
- The holes number 40 ... 49 refers to the results obtained for the fourth trial.

The results refer to the data measured on three levels, for each hole (levels situated at the start, middle and the end of each hole).

Table 5. The experimental results (raw data), of the Ra [μm] roughness parameter, for all the four trials

Hole no.	Hole's level I	Hole's level II	Hole's level III
10	4,71	5,03	4,17
11	4,27	3,99	5,32
12	5,33	3,71	4,53
13	5,13	3,56	5,00
14	4,15	4,55	3,86
15	6,03	4,31	5,65
16	5,58	3,92	3,95
17	4,49	4,51	4,74
18	4,18	4,06	4,23
19	3,67	3,82	3,33
20	5,2	4,78	3,88
21	5,15	3,92	4,42
22	3,89	3,6	5,13
23	4,32	3,97	4,7
24	4,27	4,24	4,12
25	3,77	4,33	3,38
26	4,22	3,33	4,02
27	4,64	4,37	4,31
28	3,93	4,73	3,34
29	4,02	4,18	4,45
30	4,11	4,01	4,29
31	5,42	4,58	4,72
32	5,17	4,14	5,77
33	5,18	4,84	5,19
34	4,96	5,07	5,08
35	5,99	4,55	5,82
36	4,23	4,89	4,49
37	5,55	4,79	5,49
38	5,27	3,79	5,49
39	4,36	4,14	5,02
40	5,37	5,52	5,48
41	4,68	5,05	4,55
42	5,27	5,44	5,48
43	5,16	4,89	5,06
44	4,94	4,43	4,82
45	5,43	3,32	4,67
46	4,85	4,25	4,46
47	5,27	4,5	4,14
48	4,78	4,75	4,84
49	5,17	4,19	4,88